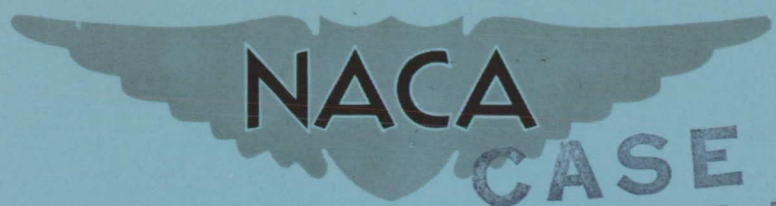


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RESEARCH MEMORANDUM

CORRELATION OF TURBOJET COMBUSTOR CARBON FORMATION
WITH SMOKE -VOLATILITY INDEX, SMOKE POINT,
AND NACA K FACTOR

By Edmund R. Jonash, Helmut F. Butze, and William P. Cook

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

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RESEARCH MEMORANDUMCORRELATION OF TURBOJET COMBUSTOR CARBON FORMATION WITH SMOKE-VOLATILITY
INDEX, SMOKE POINT, AND NACA K FACTOR

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SUMMARY

An investigation of the carbon-forming characteristics of MIL-F-5624B, grades JP-3 and JP-4, jet-engine fuels varying in smoke-volatility index was conducted in a single-tubular combustor. Combustion-chamber carbon deposits and exhaust-gas smoke densities were determined at two combustor operating conditions simulating (A) a 4-pressure-ratio engine at a 20,000-foot altitude and zero flight speed, and (B) a 7-pressure-ratio engine at sea level and a flight Mach number of 0.87.

At the lower-pressure condition (condition A), carbon deposits and exhaust-gas smoke densities correlated with three empirical fuel factors: smoke-volatility index, smoke point, and NACA K factor (function of distillation characteristics and hydrogen-carbon ratio). The best correlations of carbon deposits were obtained with the NACA K factor and the smoke point, however. At the higher-pressure condition (condition B), the deposits and smoke densities did not satisfactorily correlate with any of the fuel factors considered.

Only the carbon-deposit data for the lower-pressure condition correlated with full-scale engine deposit data previously obtained with the same fuels. The sensitivity of deposition to changes in fuel properties varied among the test units.

INTRODUCTION

Carbon formation in turbojet combustors is markedly influenced by fuel characteristics. Approximate relations have been found between carbon formation and several empirical factors derived from fuel properties (ref. 1). One such factor, the smoke-volatility index, is used in current military procurement specification MIL-F-5624B, grades JP-3 and JP-4, to limit the carbon-forming propensity of jet fuels. Smoke-volatility index is a function of the distillation characteristics of the fuel and a smoke point determined with a laboratory wick lamp.

The purpose of this report is to examine the relation between the smoke-volatility index and carbon formation in combustors with JP-3 and JP-4 fuels that vary widely in physical and chemical properties. Also, the relations obtained with the smoke-volatility index are compared with those obtained with two other fuel factors that have been used to predict carbon formation: smoke point and NACA K factor (function of distillation characteristics and hydrogen-carbon ratio of fuel).

Deposit data obtained with 10 fuels in a single-tubular combustor operated at conditions simulating a 4-pressure-ratio engine at 90-percent rated engine speed, zero flight speed, and 20,000-foot altitude are presented. Most of these fuels were special blends distributed for cooperative fuels research by the Coordinating Research Council. In order to determine the effect of operating conditions on deposition, and hence on the general applicability of the three fuel factors, six fuels were tested in the same combustor at conditions simulating operation in a 7-pressure-ratio engine at rated engine speed, Mach 0.87, and sea level. The data obtained are generally limited to carbon deposition in the combustion chamber; however, some information on exhaust-gas smoke concentration with several of the fuels is included.

In order to cover a wider range of fuel properties, single-combustor deposit data previously reported in references 2 and 3 are included in the correlations presented herein. Single-combustor data are compared with limited data obtained with the same fuels in several full-scale engines (refs. 3 and 4).

FUELS

Analyses of the fuels examined are presented in table I. The fuels reported in references 2 and 3 are included in this table. Smoke-volatility index SVI is defined as

$$\text{SVI} = \text{Smoke point} + 0.42(\text{volume percent of fuel boiling under } 4000^\circ \text{ F})$$

Fuel procurement specification MIL-F-5624B requires that the smoke point be determined by method 2107 of specification VV-L-791. Most of the fuels listed in table I were tested before the acceptance of this method. The smoke points reported for these fuels were measured with the modified Davis factor lamp described in reference 5 (noted in table I). The two test methods have been found to agree reasonably well, and no distinction between the two is made in this report. The NACA K factor reported in table I, which is a function of the volatility and hydrogen-carbon ratio of the fuel, was estimated from an enlargement of figure 3 in reference 1.

General descriptions of the fuels are given in the following table:

Fuel	Fuel type ^a	Description
50-264 51-353 52-50	JP-3	Fuels blended to investigate effects of high-boiling single-ring and dicyclic aromatic hydrocarbons (ref. 2)
52-32 52-53 52-105	JP-4	
52-117 52-118 52-119 52-120	JP-4	Fuels blended to investigate effects of low- and high-boiling aromatics; fuels were tested as part of a cooperative program sponsored by the Coordinating Research Council
52-166	JP-3	
52-28 52-76	JP-4	Fuels tested in a single combustor and in full-scale engines (ref. 3)
52-30	JP-3	
54-108 54-109 54-110 54-111	JP-4	Fuels blended to investigate effect of varying SVI; fuels were tested as part of a cooperative program sponsored by the Coordinating Research Council; they were also tested in three full-scale engines at Wright Aeronautical Development Center (ref. 4)
52-288	JP-4	A "high quality" JP-4 fuel
54-41	JP-4	A "low quality" JP-4 fuel

^a"Fuel type" refers only to the volatility characteristics of the fuels. Many of these fuels do not fall within the MIL-F-5624B specifications in all respects.

APPARATUS AND PROCEDURE

The single-combustor tests were conducted with the J33 liner and dome assembly shown in figure 1. The facility shown in figure 2(a) was used for low inlet-air pressure and temperature tests; that shown in figure 2(b) was used for higher inlet-air pressure and temperature tests. In each case air-flow rate and pressure in the combustor were controlled by remote-operated valves in the combustor inlet and outlet

ducting. The desired combustor inlet-air temperature was obtained by using either electric preheaters (fig. 2(a)) or a gasoline-fired heat exchanger (fig. 2(b)).

Air- and fuel-flow rates to the combustor were measured by means of square-edged orifice plates (installed according to A.S.M.E. specifications) and calibrated rotameters, respectively. Combustor inlet and outlet total pressures were measured with total-pressure probes connected to either manometers or strain-gage pickups. Combustor inlet and outlet temperatures were measured with iron-constantan, chromel-alumel, or platinum - platinum-rhodium thermocouple probes connected to automatic balancing potentiometers. More complete details concerning the test installations and combustor temperature and pressure instrumentation are presented in references 6 and 7.

The "smoke meter" described in detail in reference 8 was used for measuring the relative smoke density of combustor exhaust gases. In the low-pressure and -temperature facility, exhaust-gas samples were obtained from a single total-head probe that was centrally located in the exhaust duct. In the high-pressure and -temperature facility, the samples were obtained from a three-point total-head probe located in the exhaust duct.

Tests were conducted at the following combustor operating conditions:

	Condition	
	A	B
Inlet-air pressure, lb/sq in. abs	26.5	141.0
Inlet-air temperature, °F	271	640
Air-flow rate, lb/sec	2.87	12.0
Outlet gas temperature, °F	1100	1800
Combustor reference velocity, ft/sec	110	130
Approximate fuel-air ratio	0.0123	0.0178
Run time, hr	4	1.5
Approximately simulated full-scale engine conditions:		
Pressure ratio	4	7
Engine rpm, percent rated	90	100
Altitude, ft	20,000	0
Flight Mach number	0	0.87

The preceding combustor reference velocities are based on the maximum cross-sectional area of the combustor, the weight flow of air, and the density of the air at combustor inlet conditions. The conditions were chosen to represent two widely different test conditions; no

attempt was made to investigate the effect of any individual operating parameter. Of the 21 fuels, 20 were tested at condition A. Only six JP-4 fuels were tested at condition B. The run time was decreased to 1.5 hours at condition B because of limited supplies of several of the fuels and because of the limited life of the combustor inner liner at this condition.

For carbon-deposition measurements, the combustor liner and dome assembly, including the ignition plug, was cleaned with mechanical rotating brushes and weighed on a torsion-type balance prior to the test run. After the prescribed period of operation the assembly was reweighed; the difference in weight represented the amount of carbon deposition reported herein.

The concentration of smoke in the exhaust gases was measured by withdrawing samples of exhaust gas through the smoke meter at intervals during the test run. The optical densities of the smoke-covered filter disks from the smoke meter were determined by a transmission densitometer. The differences in optical density readings between the smoke-covered and clean filters are reported herein as smoke density. A more complete description of the smoke-measurement procedure is given in reference 8.

RESULTS

Carbon Deposition

Carbon-deposition data obtained in the single combustor are presented in table II. Data of references 2 and 3 are included in this table; the fuels are listed in the order of their number designations. At the lower inlet-air pressure and temperature (condition A), average deviations in individual test results from average test results varied from 1 to 18 percent. At condition B the average deviations were greater, varying from 8 to 30 percent. Poorer reproducibility of carbon-deposit data at high inlet-air temperature was also observed in reference 7.

Gray deposits were obtained with fuels 52-28, 52-166, 53-49, and 54-111 (see table II). Similar deposits have been observed in tests with fuels containing small amounts of metals (ref. 9). Spectrographic analysis of the deposits with fuel 54-111 at condition A indicated lead, which was assumed to have been present in the fuel as a contaminant. The deposits with this fuel at condition B showed no evidence of lead. It is very possible that the lead was present in the fuel as tetraethyl lead, the antiknock additive used in aviation gasoline. The high inlet-air temperature at condition B may have vaporized this volatile compound so rapidly that no significant quantity reached the carbon-forming areas

of the liner walls. Another possible explanation for the inconsistency is the fact that the fuel was received in fourteen 55-gallon drums, and only a part of the total shipment may have been contaminated.

Average deposits obtained at condition A are plotted against smoke-volatility index, smoke point, and NACA K factor in figure 3. The deposits generally increased with decrease in smoke-volatility index or smoke point, and with an increase in K factor. The solid symbols in figure 3 denote deposits that showed evidence of metal contamination. Since small quantities of metallic compounds have been found to influence deposits (ref. 9), these data points were not considered in the fairing of the correlation curves. Tailed symbols in figure 3 denote deposit data obtained prior to 1954.

Average deposits obtained at condition B are plotted against the same three fuel factors in figure 4. While the general trends are the same as those obtained at condition A, the deviations from a mean correlation curve are much greater. It is apparent from these results that there is no satisfactory relation between deposits obtained at the two conditions.

Smoke Formation

The exhaust-gas smoke data obtained with four of the fuels are presented in table III. Average percentage deviations varied from 12 to 30 percent. Because of inaccuracies in the smoke measurement technique, larger percentage deviations generally occurred at lower values of smoke density. Average smoke densities are plotted in figure 5 against smoke-volatility index, smoke point, and NACA K factor. There is evidence that at both conditions smoke density decreased with an increase in smoke-volatility index and smoke point and with a decrease in K factor. A reasonable correlation was obtained only at condition A, and only the data for this test condition were used to fair the lines shown in figure 5.

DISCUSSION

Single-Combustor Carbon Deposition

The data presented in figure 3 show that single-combustor carbon deposits obtained at the lower inlet-air temperature and pressure condition correlated reasonably well with any of three empirical fuel factors - smoke-volatility index, smoke point, and NACA K factor. The data included in the correlations were obtained over a considerable period of time, and there is some indication that the more recent data (plain symbols, fig. 3) define a correlation curve at a slightly higher level of deposit. The correlations applied equally well to JP-3 and JP-4 fuels;

furthermore, they encompassed fuels falling well outside the range of fuel properties required by current MIL-F-5624B specifications.

The relative accuracy of the three fuel factor correlations can be judged by examining deviations of the deposit data from the correlation curve. The deviations for condition A are shown in the following table:

Fuel factor	Average deviation, percent	Maximum deviation, percent	Standard error of estimate, g
Smoke-volatility index	27	95	4.0
Smoke point	17	67	3.0
NACA K factor	12	30	2.6

The average deviations were calculated from the equation

$$\text{Average deviation} = \frac{\sum \frac{y - y_c}{y_c}}{n} \times 100$$

where y and y_c are the determined and predicted values of carbon deposit, respectively, and n is the number of determinations. The standard error of estimate is another measure of the dispersion of the determined values of deposit about the correlation line and is defined

as $\sqrt{\frac{\sum (y - y_c)^2}{n}}$. Data for fuels suspected of being contaminated were not included in these calculations. Based on average deviation, maximum deviation, or standard error of estimate, both the smoke point and the K factor gave more accurate deposit correlations than did the smoke-volatility index; the smallest deviations were obtained with the K factor. Data of reference 1 show that these same two factors were the most accurate of about 10 factors examined. It should be pointed out that simplicity, as well as accuracy, is an important criterion for a satisfactory fuel procurement specification. The determination of an accurate value of hydrogen-carbon ratio, required to compute the K factor, is considerably more difficult than the measurement of smoke point.

The range of fuel properties included in the correlations of figure 3 is much greater than that permitted by current fuel specifications. For example, fuel 54-41 had accelerated and existent gum contents about 6 times those allowed by the specifications. This particular fuel produced the high values of maximum deviation noted in the smoke point and smoke-volatility index correlations. Data of reference 10 show that high values of gum content can cause increased deposits that may not be predicted by empirical fuel factors. Restricting the range of fuel properties, as provided by the specifications, would be expected to reduce deviations considerably.

At the higher inlet-air temperature and pressure (condition B; fig. 4) deposits did not satisfactorily correlate with any of the fuel factors. Preliminary examination of other fuel characteristics that could affect carbon deposition (ref. 1) did not yield any better correlation of the data. The mean straight lines drawn through the data in figure 4 are, however, approximately parallel to the corresponding correlation lines for condition A (fig. 3). In reference 11 deposit data obtained at several different operating conditions in an annular combustor also gave approximately parallel correlation lines with K factor.

The poor correlation obtained with the condition B data may be the result of more erratic carbon deposition patterns at high inlet-air temperatures. It was found in reference 7 that at such conditions carbon was deposited in isolated areas around the upstream end of the combustion chamber. Some of the heavier deposits thus formed tended to break away from the walls and were found in the exhaust ducting of the test rig. In comparison, at low inlet-air temperature conditions carbon is generally found uniformly deposited in a sizable area around the fuel nozzle of this combustor.

Full-Scale-Engine Carbon Deposition

Carbon-deposit data obtained in several full-scale turbojet engines (refs. 3 and 4) are presented in table IV. The engines were operated for approximately 50 hours (ref. 3) or 10 hours (ref. 4) at static sea-level conditions and cyclic operating schedules. The deposits listed are average values for (1) each combustion chamber in cases of tubular combustor assemblies (J33 and J47), or (2) each vaporizer tube in the case of the annular vaporizing combustor (J65). Individual chamber or vaporizer deposit values varied from the over-all average value by 11 to 32 percent in the J33 and J65 engines and by 33 to 74 percent in the J47 engine. In comparison, the variations observed in the duplicate tests with one combustor unit (table II) were from 1 to 11 percent at condition A and from 8 to 30 percent at condition B.

These data are plotted against smoke-volatility index, smoke point, and K factor in figure 6. Relatively consistent trends are obtained with all engines. Data for the two J33 engines would not be expected to fall on a single curve, since different operating conditions were used. The three fuel factors appear to correlate the engine data with about equal accuracy. The percentage deviations for each of the correlations were not computed because of the limited number of fuels tested.

Carbon deposition in the several full-scale engines was affected to a varying degree by changes in fuel properties. For example, deposits in the J65 engine increased only about 40 percent, and those in the J47,

about 400 percent, when the smoke-volatility index was decreased from 56 to 44. Neither the absolute level of deposition nor the relative effects of fuel factor on these deposits shown in figure 6 should be used to distinguish between good and bad combustor design. The data do not give any indication of the relative tolerance of the various engines to carbon deposition. Furthermore, although weight of deposit is used here as the measure of carbon formation, the volume of the deposits may be much more important, insofar as combustor performance is concerned.

Since fuels research can be conducted more economically in single-combustor test rigs, the relation between results obtained in such rigs and those obtained in the actual full-scale engine should be examined. The correlation curves for the single combustor at condition A (fig. 3) are included in figure 6 to show that the same general trends were obtained in both full-scale engine and single-combustor tests. The relation between single J33 combustor and full-scale J33 engine deposits, including only fuels tested in both units, is shown in figure 7. At condition A fuels that gave larger deposits in the single combustor also gave larger deposits in the full-scale engine; however, deposits in the single combustor increased at a much more rapid rate as fuel "quality" decreased. The variation in sensitivity between the single combustor and full-scale engine is at least partially attributable to differences in operating conditions. The full-scale engines were operated on a cyclic test schedule; whereas, the single combustor was operated at constant operating conditions. Also, the combustor inlet and outlet passage configurations were different in the single combustor and the full-scale engine.

Single-combustor data for condition B are included in figure 7. As would be expected, no relation is apparent for these data.

Smoke Formation

The measured values of smoke density were generally very low and may be of questionable significance. Nevertheless, they did vary with fuel properties in much the same way as did carbon deposition; that is, smoke formation generally decreased with an increase in smoke-volatility index or smoke point and with a decrease in K factor (fig. 5). Satisfactory relations were obtained only at condition A. While these results indicate that smoke formation and carbon deposition are affected by the same factors, experience has shown that design features tending to alleviate the carbon-deposition problem frequently aggravate the smoke problem and vice versa. Also, data presented in reference 8 show that, while fuel volatility affected smoke density in a single combustor, the effects were very different at different operating fuel-air ratios. This might explain the fact that correlations with fuel factors were obtained at one condition and not at another in the present investigation. It should also be pointed out that the empirical fuel factors considered were developed for carbon deposition and not for exhaust-gas smoke.

SUMMARY OF RESULTS

From investigations of the carbon-forming characteristics of MIL-F-5624B grades JP-3 and JP-4 jet engine fuels in a single-tubular combustor, the following results were obtained:

1. At operating conditions simulating a 4-pressure-ratio engine at a 20,000-foot altitude and zero flight speed, carbon deposits and exhaust-gas smoke density correlated with smoke-volatility index, smoke point, and NACA K factor of the fuel. More accurate correlations of deposits were obtained with smoke point and NACA K factor.
2. Single-combustor deposit data at the preceding conditions also correlated reasonably well with limited full-scale engine deposit data previously obtained with the same fuels. Deposition in different test units was not, however, equally sensitive to changes in fuel properties.
3. At operating conditions simulating a 7-pressure-ratio engine at sea level and Mach 0.87, neither deposits nor smoke density satisfactorily correlated with any of the fuel factors considered. Also, the deposit data obtained at these conditions did not correlate with full-scale engine data.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, May 2, 1955

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TABLE I. - FUEL PROPERTIES

A.S.T.M. distillation, D 86-52. °F % Evaporated	MIL-F-5624B		NACA fuel								
	Grade JP-3	Grade JP-4	50-264	51-353	52-28	52-30	52-32	52-50	52-53	52-76	52-105
Initial point	-----	-----	100	124	137	119	128	114	136	142	134
5	-----	-----	120	170	178	167	189	167	183	201	183
10	-----	-----	152	205	194	199	234	205	200	220	204
20	240 (max.)	270 (max.)	224	260	217	244	304	263	225	244	231
30	-----	-----	268	295	236	272	350	293	244	263	253
40	-----	-----	301	322	256	295	397	322	263	283	272
50	350 (max.)	370 (max.)	330	358	275	316	422	356	278	304	291
60	-----	-----	368	401	299	337	434	401	301	324	314
70	-----	-----	413	428	317	362	442	425	321	348	343
80	-----	-----	444	445	347	401	449	451	347	381	381
90	470 (max.)	470 (max.)	477	469	400	460	458	474	400	438	431
End point	-----	-----	512	512	486	517	500	516	498	494	488
Residue, %	1.5	1.5	1.2	1.3	1.2	1.4	1.1	1.2	1.2	1.2	0.9
Loss,	1.5	1.5	1.8	0.3	0.6	1.1	0.4	0.8	0.7	0.8	0.3
Freezing point, °F	-76 (max.)	-76 (max.)	< -76	---	---	---	---	---	---	< -76	---
Reid vapor pressure, lb/sq in.	5.0-7.0	2.0-3.0	6.0	---	2.8	5.4	2.6	---	2.9	2.3	---
Aromatics, % by volume	25.0 (max.)	25.0 (max.)	26	---	10	---	---	---	10.7	24	---
Bromine number	-----	-----	8.0	---	---	---	---	---	---	---	---
Accelerated gum, mg/100 ml	14 (max.)	14 (max.)	12	---	---	---	---	---	---	3	---
Existent gum, mg/100 ml	7 (max.)	7 (max.)	9	---	---	---	---	---	---	1	---
Hydrogen-carbon ratio ^a	-----	-----	0.153	0.152	0.171	0.168	0.149	0.148	0.170	0.156	0.160
Heat of combustion ^c , Btu/lb	18,400 (min.)	18,400 (min.)	18,460	18,400	18,725	18,675	18,275	18,350	18,700	18,475	18,575
Aniline-gravity product	5250 (min.)	5250 (min.)	5119	4441	7460	6945	3138	3942	7335	5133	6059
Specific gravity, 60°/60° F	-----	-----	0.791	0.804	0.756	0.771	0.822	0.816	0.757	0.787	0.779
Gravity, °A.P.I.	50-60	45-55	47.3	44.5	55.8	52.1	40.6	41.8	55.4	48.2	50.2
Aniline point, °F	-----	-----	108.8	99.8	133.7	133.3	77.3	94.3	132.4	106.5	120.7
Smoke-volatility index	54.0 (min.)	54.0 (min.)	45.5	38.9	78	66	28.2	36.9	72.3	51	59.3
Smoke point, mm	-----	-----	d _{17.2}	d _{13.9}	d _{40.0}	d _{32.3}	d _{11.0}	d _{11.9}	d _{34.5}	d _{16.5}	d _{24.0}
NACA K factor ^f	-----	-----	331	341	252	277	363	353	258	316	300

^aDetermined by combustion furnace.^bMethod not listed.^cEstimated from aniline-gravity constant.^dDetermined by modified Davis factor lamp (ref. 5).^eDetermined by method 2107 of specification VV-L-791.^fRef. 1.

TABLE I. - FUEL PROPERTIES

NACA fuel											
52-117	52-118	52-119	52-120	52-166	52-288	53-49	54-41	54-108	54-109	54-110	54-111
135	144	143	139	105	139	130	146	130	136	170	146
200	207	208	202	142	224	205	198	171	176	220	192
233	229	233	226	175	253	247	235	210	217	240	224
278	257	266	261	243	291	310	278	273	267	268	267
322	284	295	291	289	311	348	312	324	304	288	295
366	318	328	338	320	324	376	339	356	329	312	321
390	358	354	379	351	333	395	359	372	348	334	341
409	393	382	404	389	347	418	393	386	367	352	361
430	418	405	426	419	363	435	434	399	385	378	381
455	446	437	445	446	382	452	477	410	403	406	407
485	479	473	467	470	413	474	521	426	423	438	445
536	533	533	532	515	486	510	572	475	476	499	514
1.7	1.7	1.5	1.1	1.3		---	1.2	1.0	1.2	1.5	1.5
0.3	0.4	0.3	0.4	0.8		---	0.8	1.0	0.8	0	0.5
<-76	<-76	<-76	<-76	<-76	<-76	<-76	<-76	<-76	<-76	<-76	<-76
2.1	1.9	1.9	2.0	6.1	2.7	2.3	2.3	2.0	2.4	1.7	2.4
3	19	27	26	24	10	14	26.5	26.9	28.1	16.3	22.1
2.5	2.9	2.4	4.9	10.6	----	2.0	7.0	----	----	----	----
21	12	22	23	51	----	12	80	85.7	34.7	5.1	15.3
4	5	5	11	18	----	3	51	4.1	1.9	2.3	5.6
0.181	0.168	0.163	0.156	0.152	0.168	^b 0.161	0.149	0.152	0.154	0.164	0.158
19,050	18,825	18,700	18,650	18,425	18,675	18,525	18,300	18,400	18,450	18,600	18,475
10,518	8353	7212	6844	4703	6950	5547	4160	4355	4888	6383	5455
0.752	0.768	0.778	0.791	0.800	0.776	0.811	0.825	0.803	0.793	0.785	0.794
56.7	52.7	50.4	47.3	45.4	50.8	43.0	40.0	44.8	47.0	48.8	46.7
185.5	158.5	143.1	144.7	103.6	136.8	129.0	104.0	97.2	104.0	130.8	116.8
68.2	54.4	49.5	42.6	42.3	68.3	43	40.1	43.8	49.5	55.9	49.4
^d 45.1	^d 28.1	^d 21.0	^d 18.0	^d 15.6	^d 32.0	^e 21.0	^e 13.7	^e 14.2	^e 17.0	^e 23.6	^e 17.1
227	285	304	332	338	278	321	357	341	330	295	318

^a Determined by combustion furnace.^b Method not listed.^c Estimated from aniline-gravity constant.^d Determined by modified Davis factor lamp (ref. 5).^e Determined by method 2107 of specification VV-L-791.^f Ref. 1.

TABLE II. - SINGLE-COMBUSTOR DEPOSITS

NACA fuel	Carbon deposits, g				Average deposits, g	Average variation, percent (a)	Reference
	Run						
	1	2	3	4			
Condition A							
50-264	9.2	12.8	11.6	10.4	11.0	11	2
51-353	13.5	15.4	14.3		14.4	5	2
52-28	----	----	----		b,c 2.5	--	3
52-30	----	----	----		c 3.7	--	3
52-32	16.1	17.9	17.5		17.2	4	2
52-50	14.4	13.9	14.0		14.1	1	2
52-53	2.2	2.4	----		2.3	4	2
52-76	----	----	----		c 7.4	--	3
52-105	6.4	6.8	----		6.6	3	2
52-117	1.1	1.2	1.3		1.2	5	-
52-118	4.8	5.4	4.9		5.0	5	-
52-119	6.8	6.8	6.1		6.6	5	-
52-120	11.4	12.0	13.1		12.2	5	-
52-166	b 7.2	b 7.7	b 7.1		b 7.3	3	-
53-49					b,c 6.9	--	3
54-41	21.4	23.3	24.0		28.0	24.7	9
				26.8			
54-108	16.2	17.0	16.3		16.5	2	-
54-109	13.9	15.3	15.5		14.9	5	-
54-110	8.1	6.4	6.4		7.0	11	-
54-111	b 8.9	b 6.0	b 9.0		b 8.0	18	-
Condition B							
52-288	3.3	2.4			2.9	16	-
54-41	7.0	9.2	6.3		7.5	15	-
54-108	5.2	2.8	----		4.0	30	-
54-109	11.0	9.0	----		10.0	10	-
54-110	6.3	5.4	----		5.9	8	-
54-111	2.3	3.5	----		2.9	21	-

^aArithmetical average percent variation of individual carbon deposition values from arithmetical average deposition value.

^bGray deposits.

^cAverage of two or more tests.

TABLE III. - SINGLE-COMBUSTOR SMOKE DATA

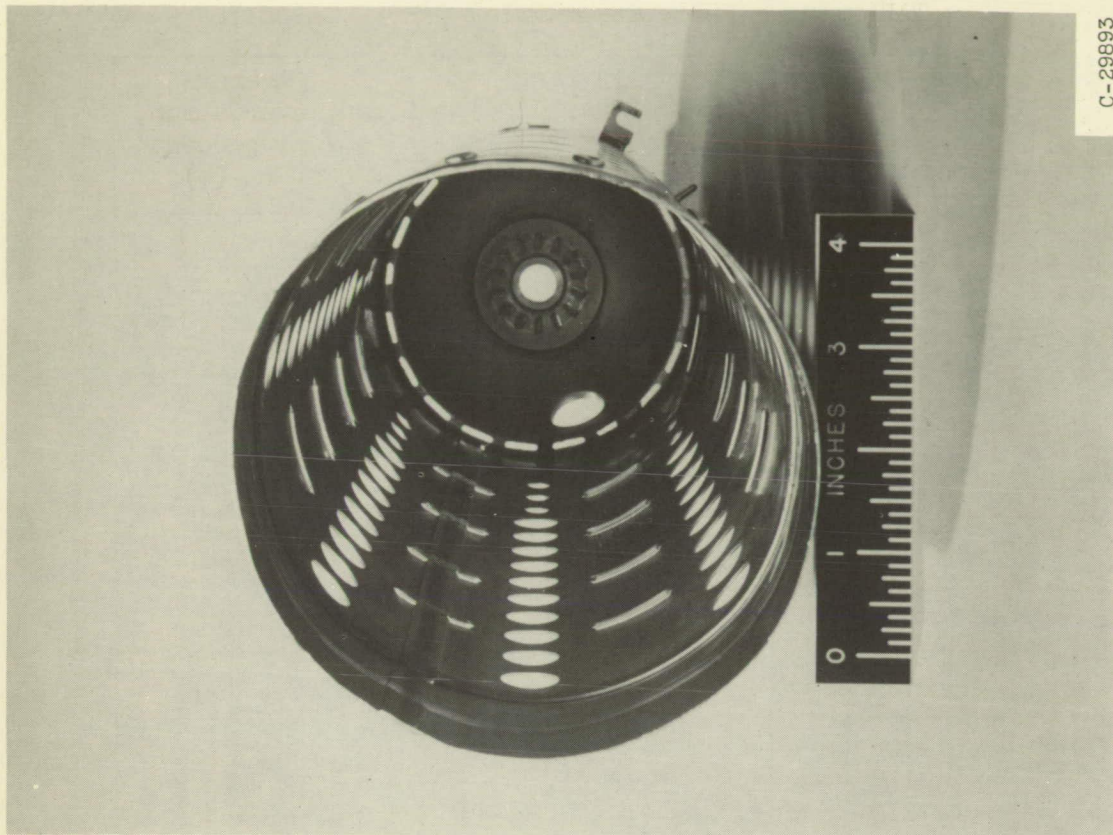
NACA fuel	54-108		54-109		54-110		54-111	
Condition	A	B	A	B	A	B	A	B
Smoke density	0.14	0.28	0.18	0.31	0.07	0.13	0.13	0.12
	.10	.37	.14	.28	.06	.18	.13	.10
	.14	.29	.12	.41	.09		.13	.15
	.18		.13	.46	.05		.11	.16
	.21		.19		.03		.09	
	.16		.20		.03		.11	
	.18		.20		.04		.13	
	.13		.14		.05		.07	
	.10							
Average smoke density	0.15	0.31	0.14	0.37	0.05	0.16	0.11	0.13
Average deviation, %	20	12	19	19	30	16	16	17

TABLE IV. - FULL-SCALE ENGINE CARBON DEPOSITS

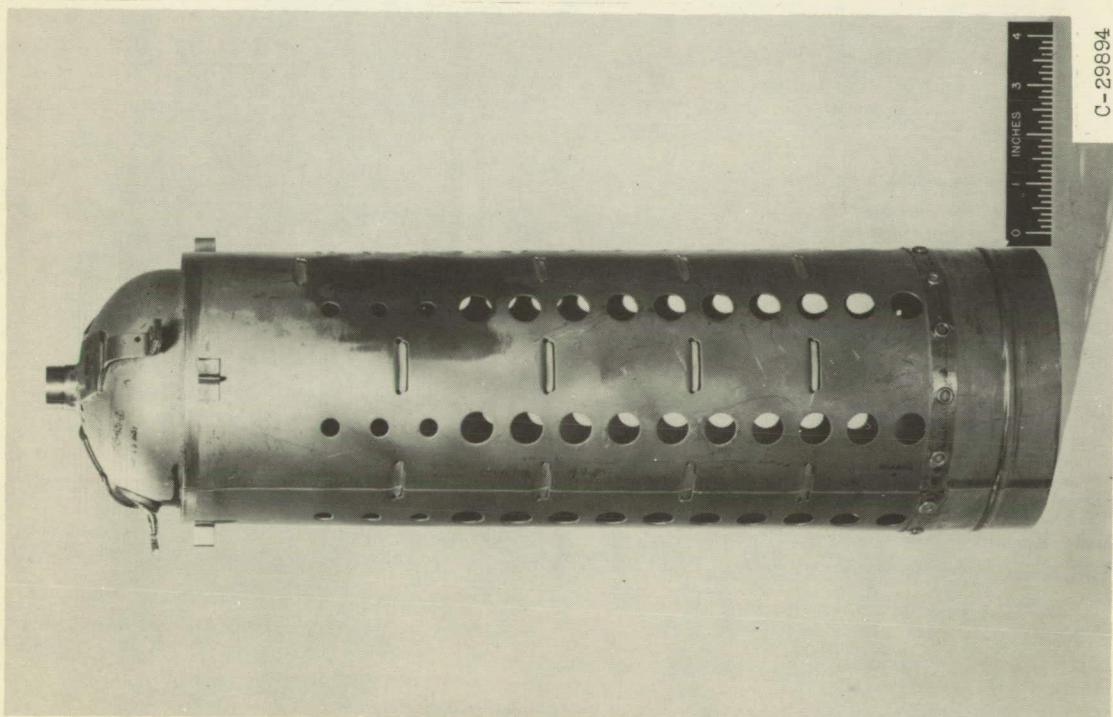
NACA fuel	Fuel designation from ref. 4	Average carbon deposition, g (a)	Average variation, percent (b)
J33 (ref. 4)			
54-108	RAF 94-53	45.9	16
54-109	RAF 95-53	45.3	12
54-110	RAF 96-53	39.0	11
54-111	RAF 97-54	43.0	15
J65 (ref. 4)			
54-108	RAF 94-53	2.28	18
54-109	RAF 95-53	2.15	28
54-110	RAF 96-53	1.57	26
54-111	RAF 97-54	1.69	32
J47 (ref. 4)			
54-108	RAF 94-53	10.4	74
54-109	RAF 95-53	3.2	74
54-110	RAF 96-53	1.9	65
54-111	RAF 97-54	6.0	33
J33 (ref. 3)			
52-28		14.9	22
52-30		22.4	18
52-76		26.0	16

^aArithmetical average deposits in each combustor or fuel vaporizer.

^bArithmetical average percent variation of deposits in individual combustion chambers, or fuel vaporizers, from arithmetical average deposit values.

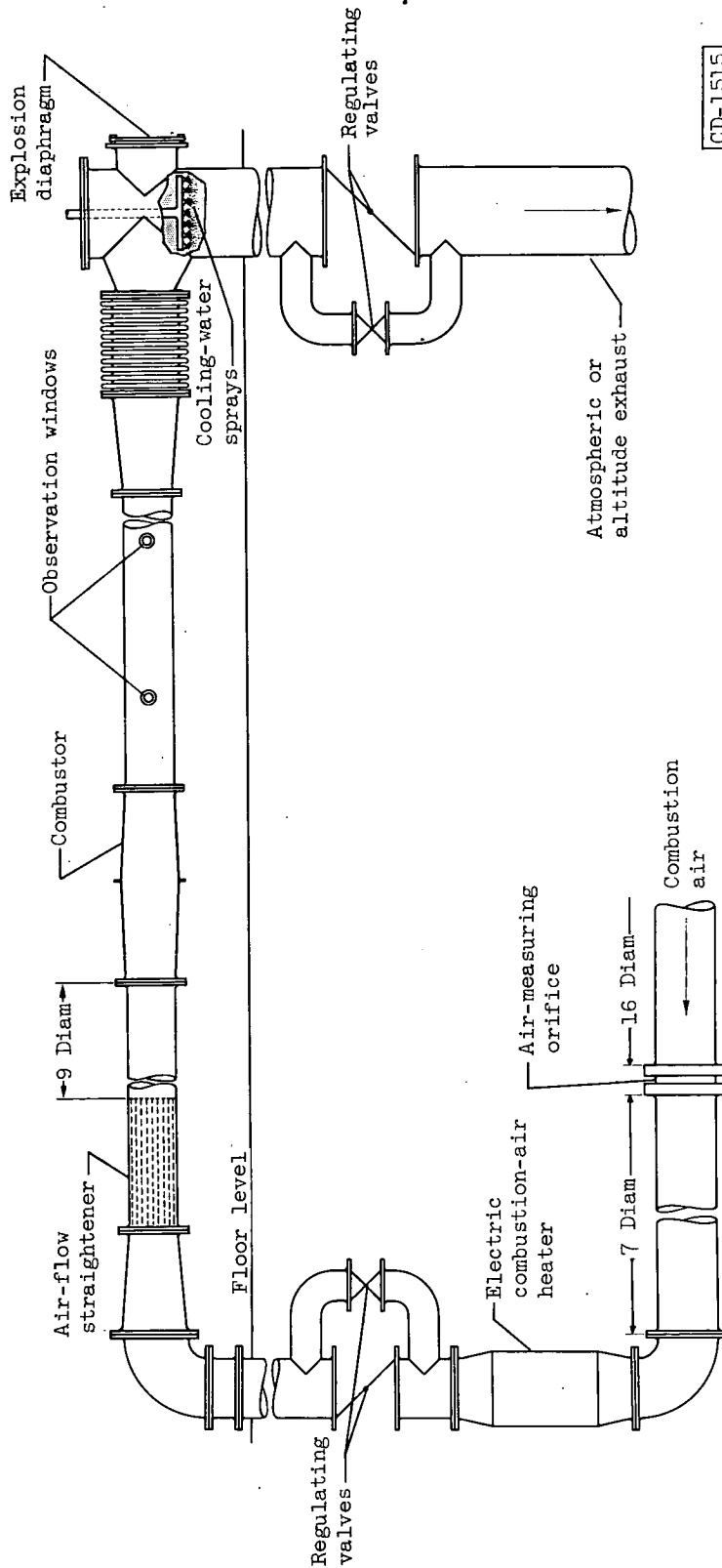


C-29893



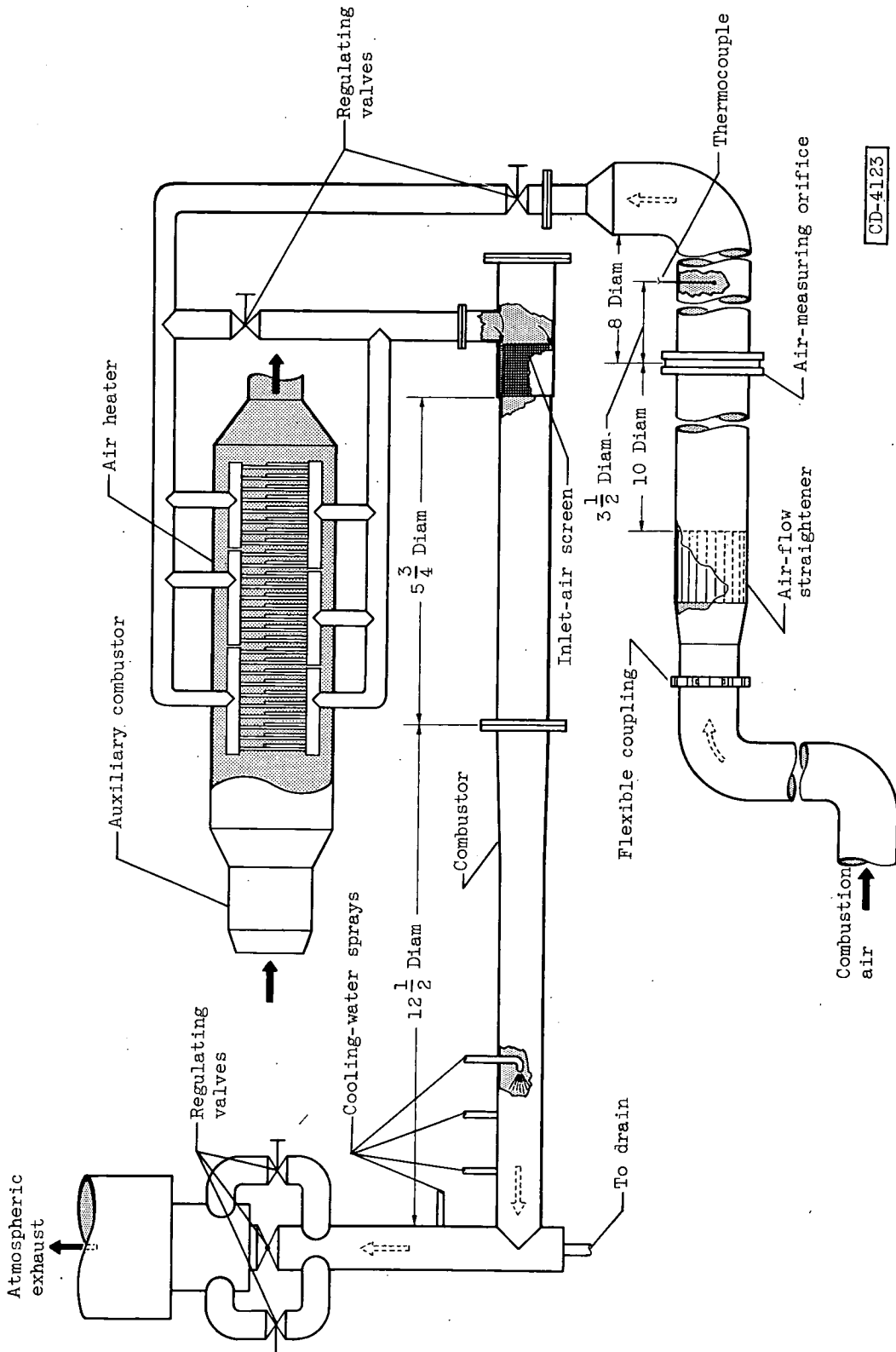
C-29894

Figure 1. - Inner liner and dome of J33 single combustor used in carbon-deposition investigation.



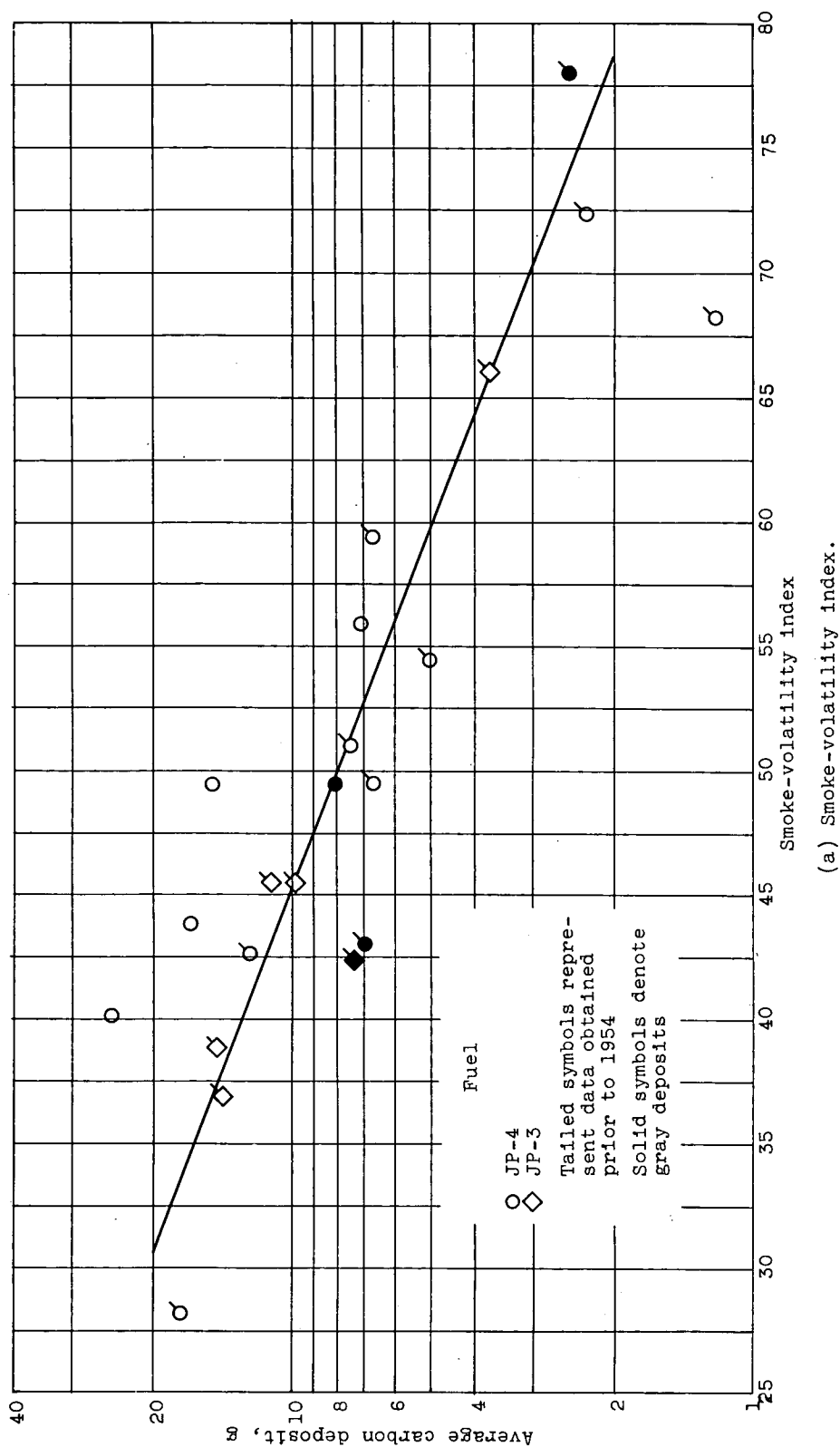
(a) Low-pressure facility.

Figure 2. - Single-combustor installation and auxiliary equipment.



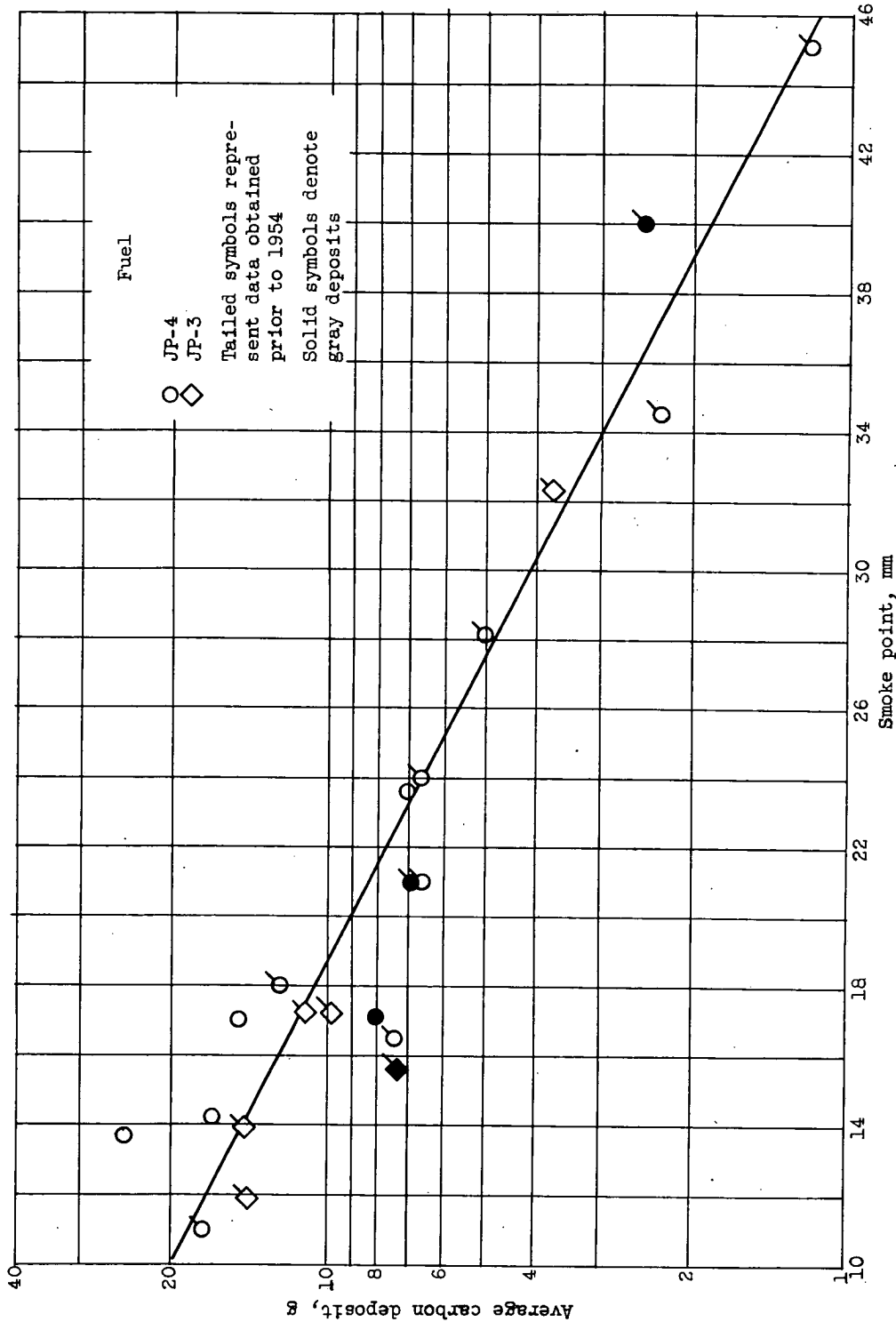
(b) High-pressure facility.

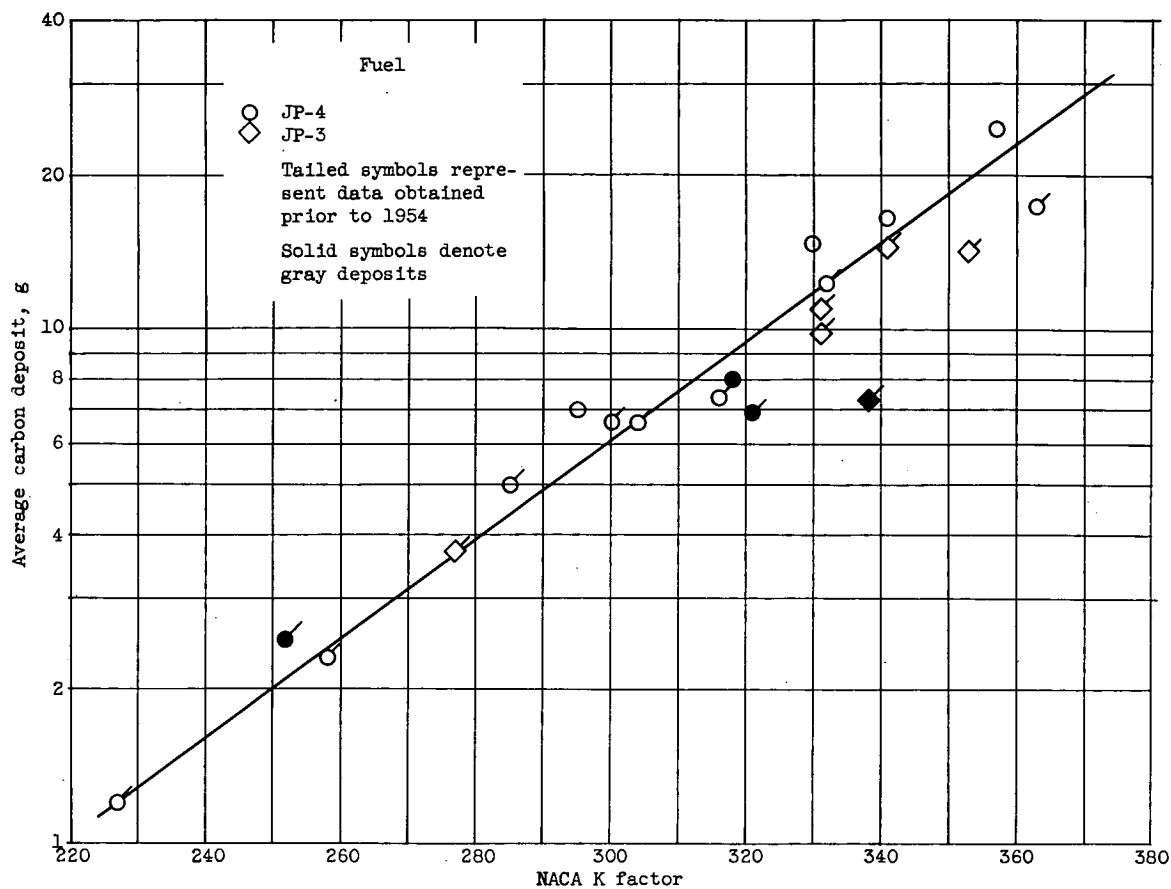
Figure 2. - Concluded. Single-combustor installation and auxiliary equipment.



(a) Smoke-volatility index.

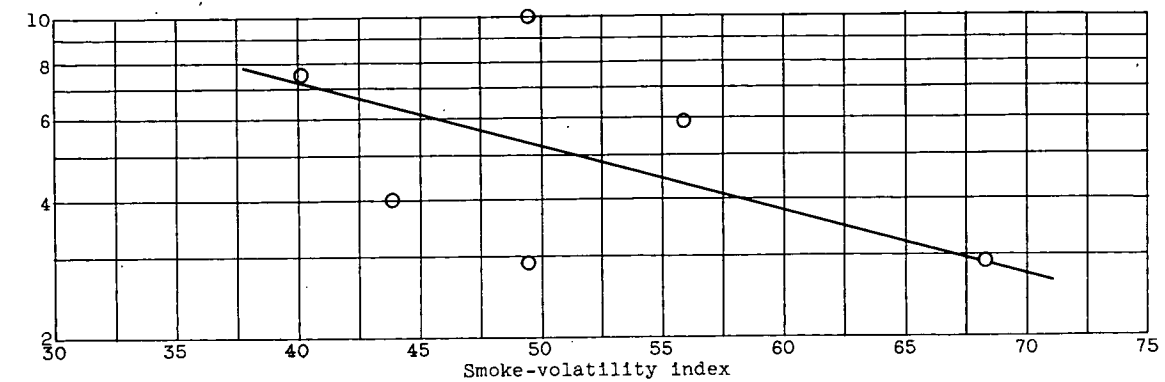
Figure 3. - Relation between average carbon deposits in single-tubular combustor and empirical fuel factors.
 Condition A: inlet-air pressure, 26.5 pounds per square inch absolute; inlet-air temperature, 271° F;
 reference velocity, 110 feet per second; outlet temperature, 1100° F.



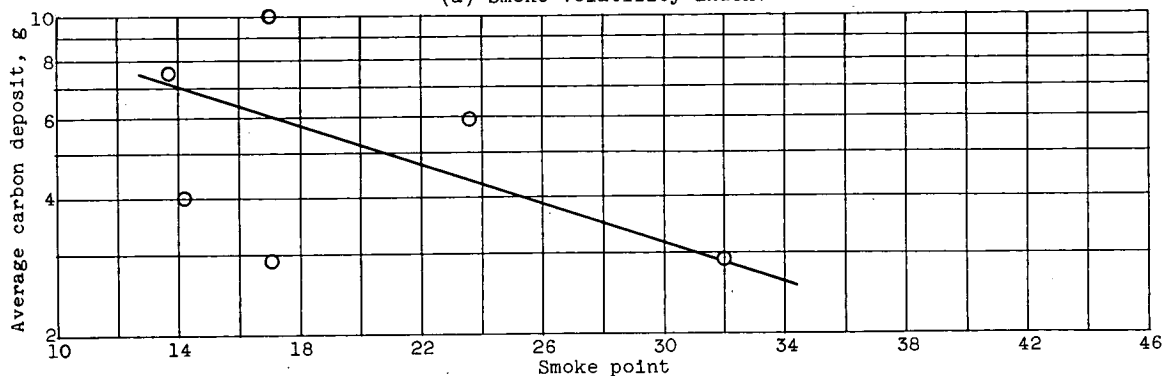


(c) NACA K factor.

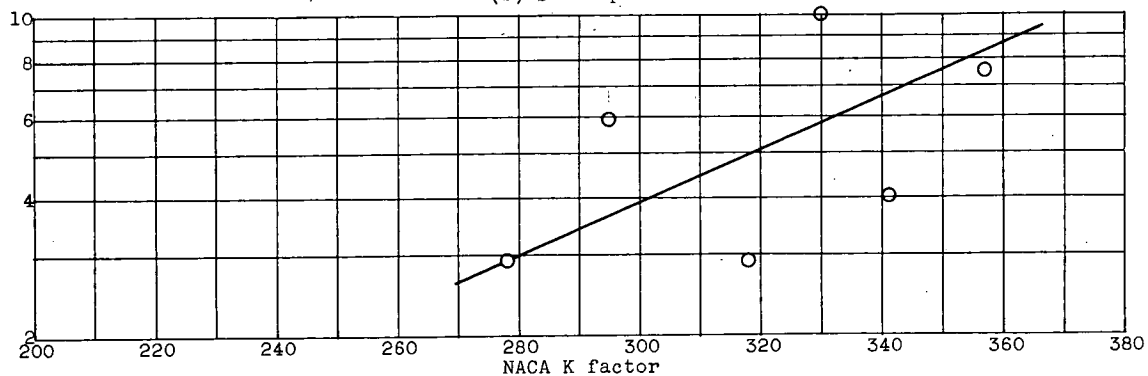
Figure 3. - Concluded. Relation between average carbon deposits in single-tubular combustor and empirical fuel factors. Condition A: inlet-air pressure, 26.5 pounds per square inch absolute; inlet-air temperature, 271° F; reference velocity, 110 feet per second; outlet temperature, 1100° F.



(a) Smoke-volatility index.

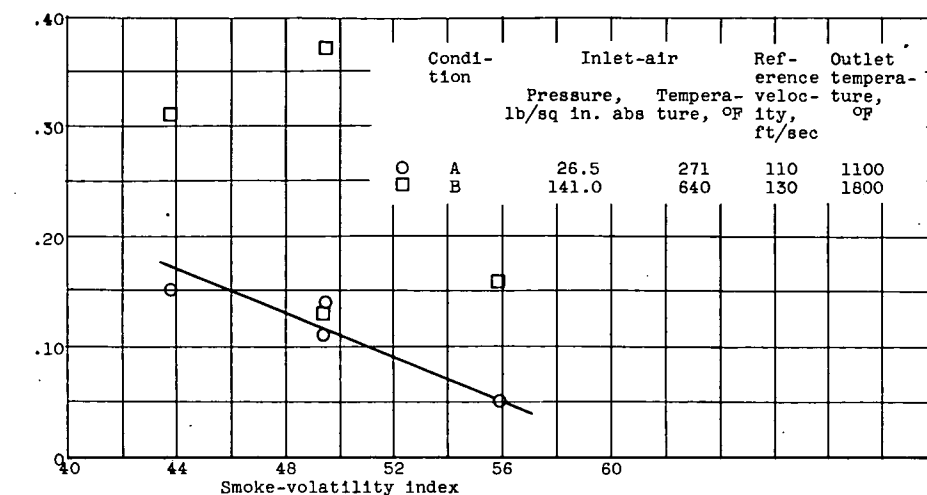


(b) Smoke point.

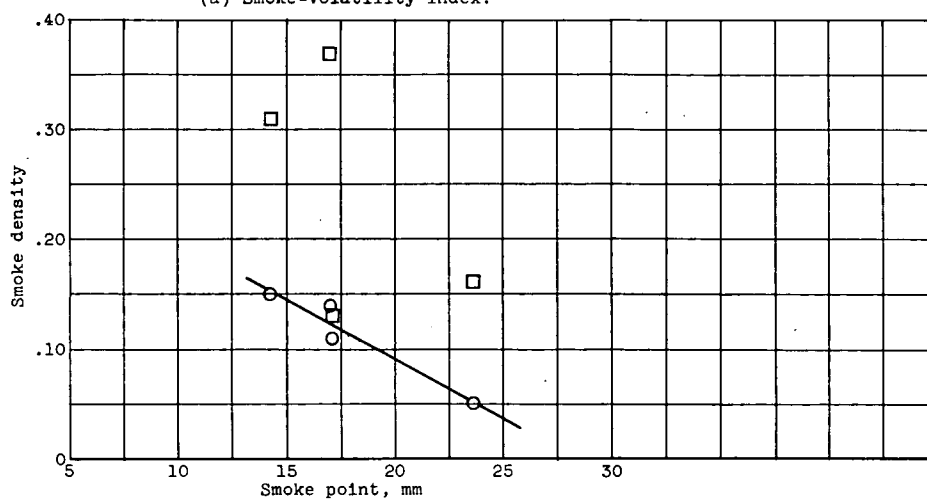


(c) NACA K factor.

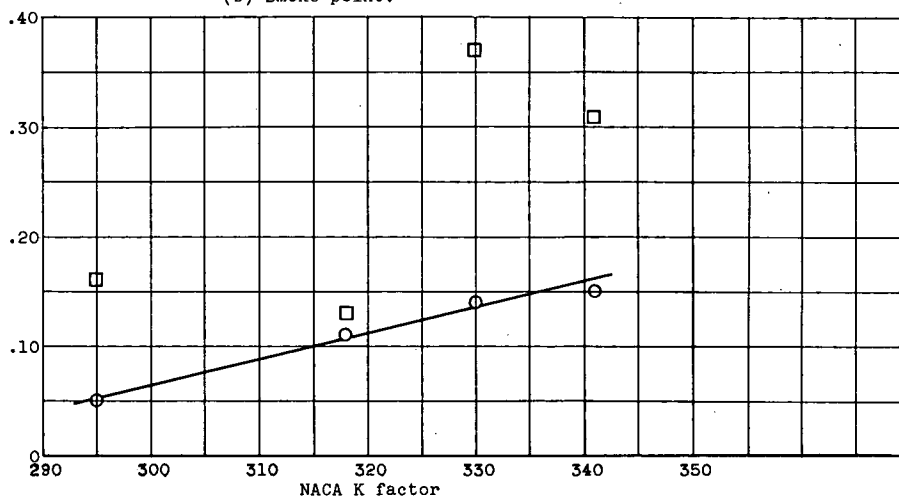
Figure 4. - Relation between average carbon deposits in single-tubular combustor and empirical fuel factors. Condition B: inlet-air pressure, 141.0 pounds per square inch absolute; inlet-air temperature, 640° F; reference velocity, 130 feet per second; outlet temperature, 1800° F.



(a) Smoke-volatility index.

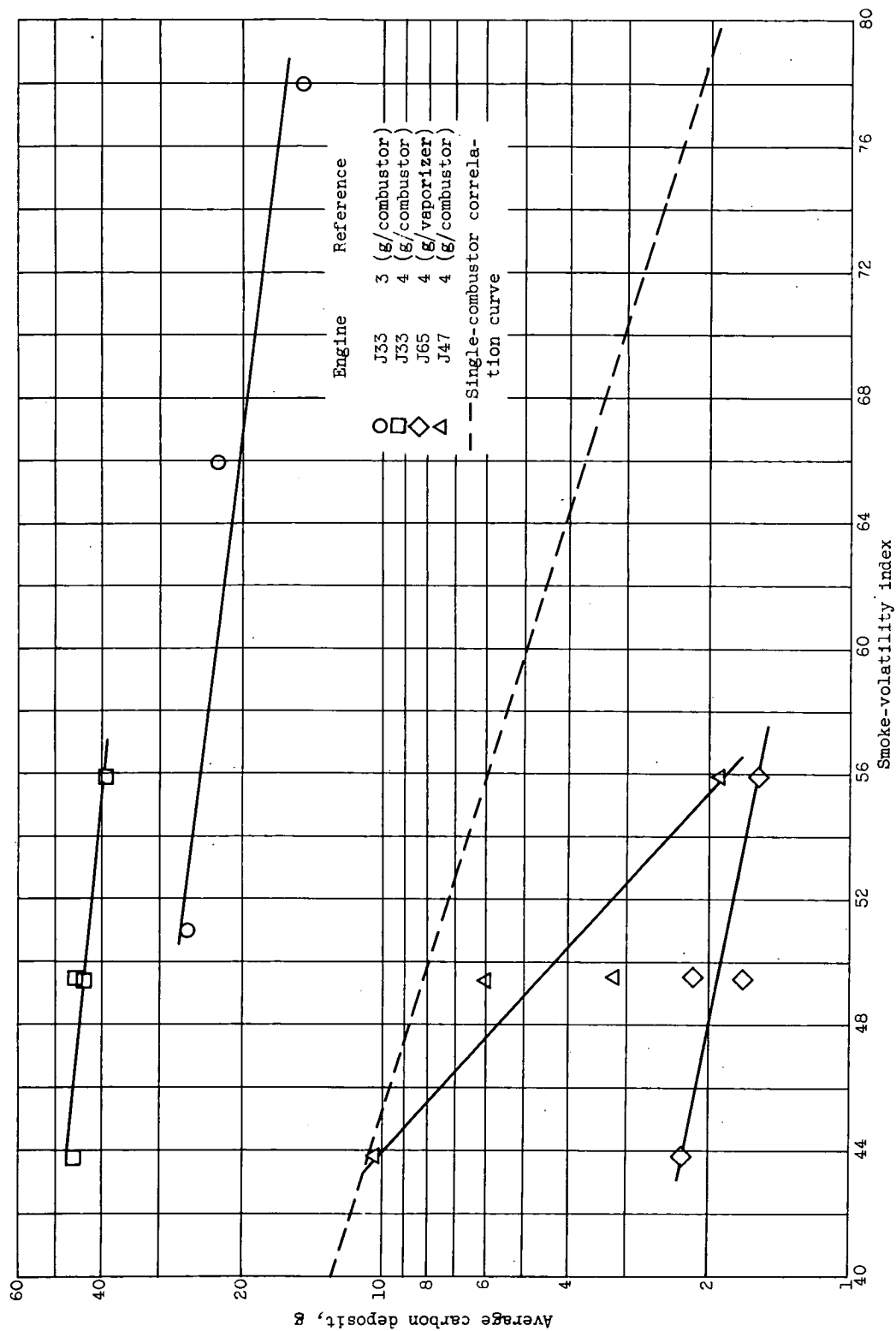


(b) Smoke point.



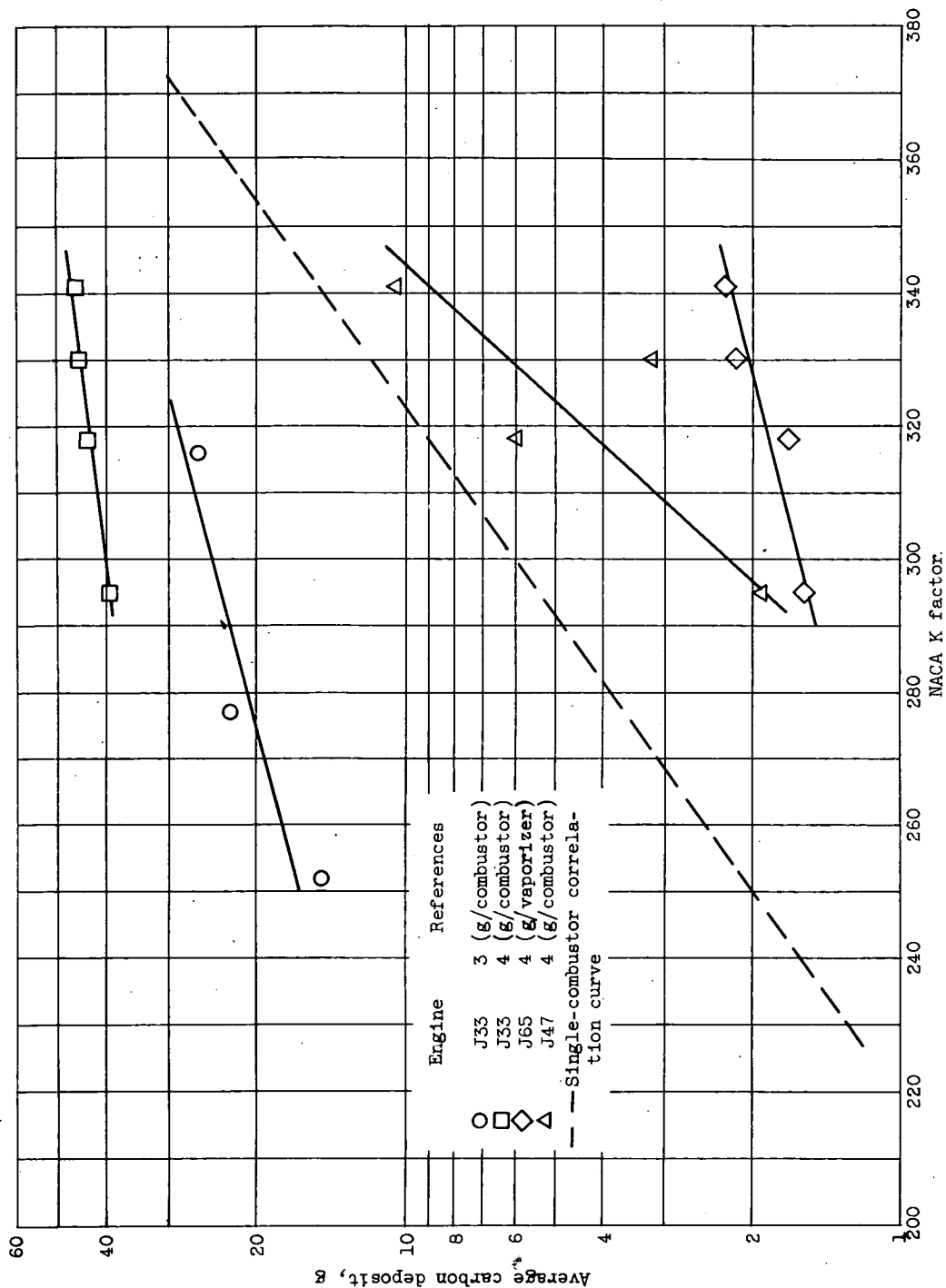
(c) NACA K factor.

Figure 5. - Relation between exhaust-gas smoke density obtained with JP-4 fuels and empirical fuel factors.



(a) Smoke-volatility index.

Figure 6. - Relation between carbon deposits in full-scale turbojet engines and empirical fuel factors.



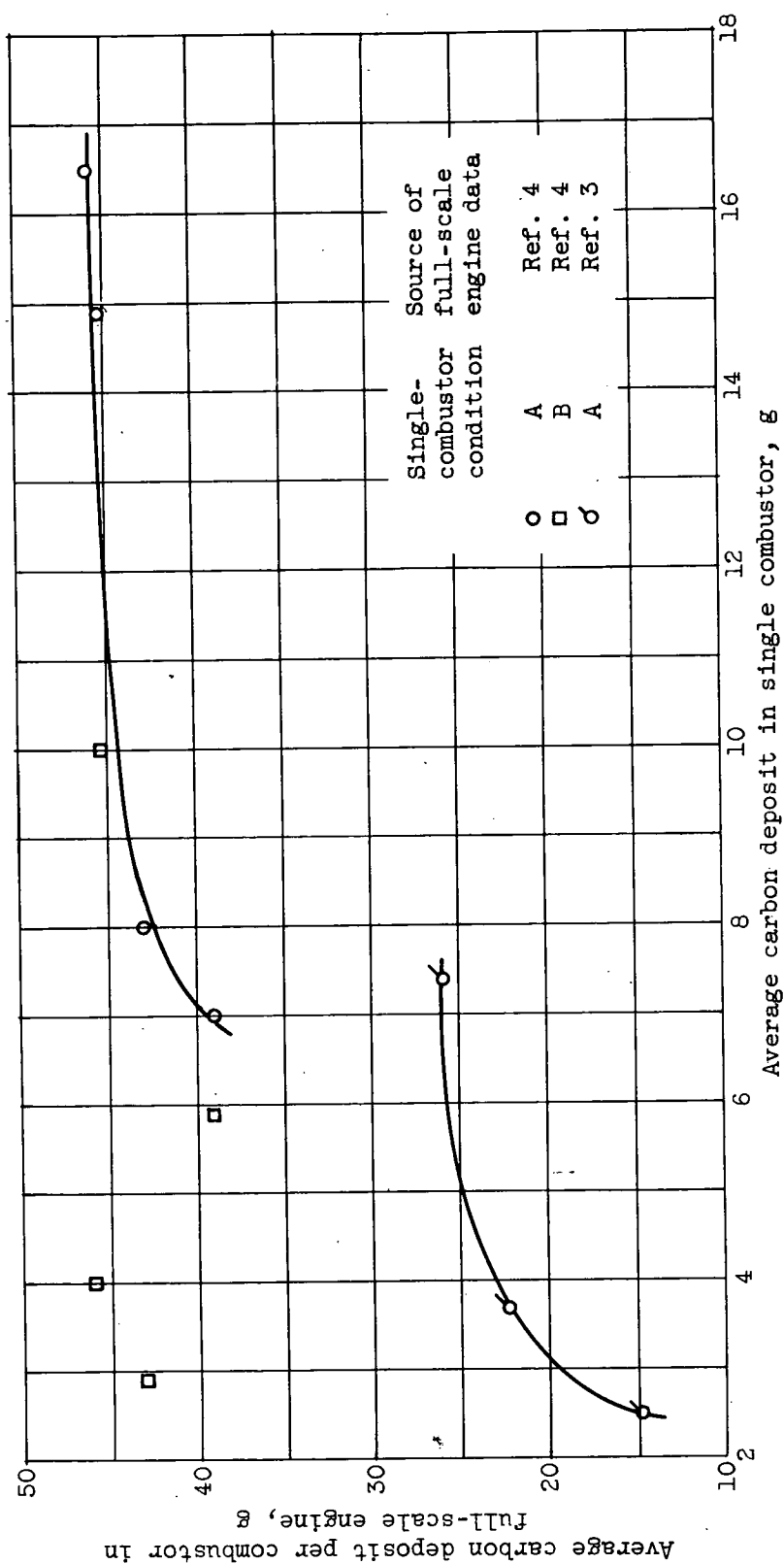


Figure 7. - Relation between carbon deposits in single combustor and full-scale engine having similar combustors.

